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Periacetabular osteotomy using three-dimensional cutting and reposition guides: a cadaveric study

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ABSTRACT

The goal of periacetabular osteotomy (PAO) is to reorient the acetabulum in a more physiological position. Its realization remains challenging regarding the final position of the acetabulum. Assistance with custom cutting- and reorientation-guides would thus be very helpful. Our purpose is to present a pilot study on such guides. Eight cadaveric hemipelvis were scanned using CT. After segmentation, 3D models of each specimen were created, a PAO was virtually performed and reorientation of the acetabula were defined. A specific guide was designed aiming to assist in iliac, posterior column and superior pubic ramus cuts as well as in acetabulum reorientation. Furthermore, the acetabular position was planned. Three-dimensional printed guides were used to perform PAO using the modified Smith-Peterson approach. The post-operative CT images and virtually planned acetabulum reorientation were compared in terms of acetabular index (AC), lateral centre edge angle (LCE), acetabular anteversion angle (AcetAV). There was no intra-articular or posterior column fracture seen. Two cadavers showed very low bone quality with insufficient stability of fixation and were excluded from further analysis. Correlation between the post-operative result and planning of the six included cadavers revealed the following mean deviations: 5° (SD ±3°) for AC angle, 6° (SD ±4°) for LCE angle and 15° (SD ±11°) for AcetAV angle. The use of 3D cutting and reorientation blocks for PAO was possible through a modified Smith-Peterson approach and revealed accurate fit to bone, accurate positioning of the osteotomies and acceptable planned corrections in cadavers with good bone quality.

INTRODUCTION

Periacetabular osteotomy (PAO) is a well-established procedure for the treatment of skeletally mature hip dysplasia [1] as well as femoroacetabular impingement due to true acetabular retroversion. The goal of PAO is to reorient the acetabulum in a more physiologic position [2]. Obtaining this ideal acetabular correction is challenging [3] because the final position of the acetabular fragment must lie within a narrow 3D range. Furthermore, the osteotomy planes must keep the pelvic ring intact while remaining extra-articular [4, 5].

Traditional PAO techniques have utilized intra-operative fluoroscopy in order to verify the accuracy and location of osteotomy cuts. Fluoroscopy was one feature to

try to perform a more accurate and safe correction in PAO surgery. However, fluoroscopy still is limited by delivering 2D information for the surgeon and therefore it is also only possible to be as accurate as the 2D planning pre-operatively. Prior work has been done to study other techniques to improve acetabular reorientation with the help of computer navigation [6]. This technique may be limited by additional operating room equipment, modified surgical exposures and additional surgical time.

Patient specific cutting- and reorientation-guides may be a useful adjunctive intra-operative tool to reduce intra-operative fluoroscopy use, to reduce operative time, and to increase the accuracy of the 3D pelvic osteotomy. In particular, this new technology might be able to optimize load

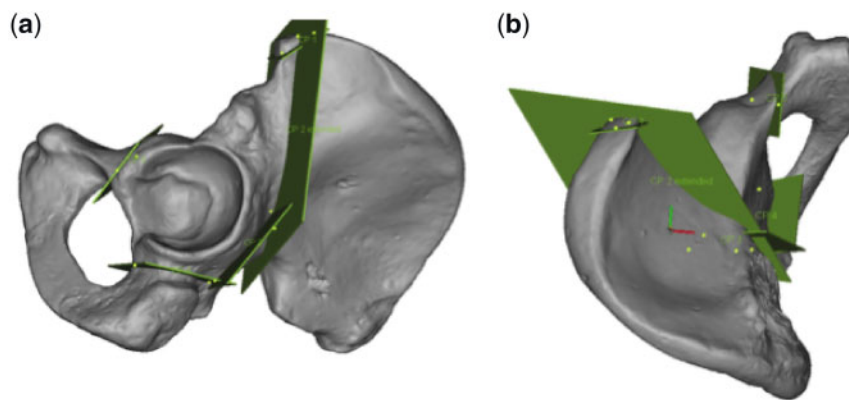


Fig. 1. In these figures, all four cuts of the PAO not involving the posterior column are shown in this 3D model of a left hemipelvis. (a) Lateral view is seen and (b) a top view is shown.

distribution without compromising on hip range of motion. In order to plan an individually adapted PAO the CT planning is mandatory and to execute this 3D plan the patient specific guide could be a valuable possibility.

While custom guides and individualized templates have been employed in other types of orthopaedic procedures [7, 8] and other pelvic osteotomies [9–11], the application in PAO as characterized by Ganz has been presented only once by Zhou *et al.* [12]. However, Zhou *et al.* did not perform the PAO surgery as described by Ganz *et al.* [13] through a modified Smith-Peterson approach, but on bony cadaver after extensive soft tissue stripping.

The purpose of this report is to present the results of a cadaveric pilot study using CT-based custom-made guides for PAO on the one hand focusing on the precise cuts respecting the anatomy and the approach and on the other hand on the reorientation. Therefore the feasibility and accuracy of these 3D guides were particularly important to the authors.

MATERIALS AND METHODS

Eight Thiel-fixed cadaveric (six females, two males) specimen, with a mean age of 85 years (range 56–100), were obtained and utilized according to the institutional guidelines and with informed consent of the donors prior to death or appropriate family members. The local institutional review board waived the need for ethical approval (BASEC-Nr. Req-2016-00517).

Preparation and planning

The cadaver hemipelvis were scanned using a high-resolution computer tomographic scanner (Siemens CT) with voxel size of $0.65 \times 0.65 \times 1.25$ mm. After segmentation of the images using Mimics[®] software (Materialise,

Leuven, Belgium), editable 3D models of each specimen were created.

A virtual PAO was performed using the partial ischial cut, the pubic cut, the iliac cut and then the completion in the ischium preserving the posterior column on the 3D models (*in silico*) (Fig. 1a and b) and reorientation of the acetabulum was defined arbitrary to a higher lateral centre edge angles (LCE) and a reasonable anteversion. Using 3-matic[®] software, an anatomy-specific guide was designed for assisting in the cadaveric supracetabular (Figs 2–6), posterior column and superior pubic ramus cuts. The partial ischial cut was not guided because of the lack of access during the real procedure.

Furthermore, the reorientation-guides were planned to achieve the intended acetabular reorientation. Position, length and trajectory of the fixation screws were calculated. All the guides (cutting- and reorientation guides) were individually manufactured for performing PAO on the respective cadaveric specimen. One example of a reposition guide is shown in Fig. 7a and b.

Surgical procedure

PAO according to Ganz *et al.* [13] through the modified Smith-Peterson approach was performed using original instruments by two fellowship trained hip surgeons.

The cadaver hemipelvis were in supine position and a modified Smith-Peterson approach was used with an osteotomy of the anterior iliac spine. In the interval of sartorius and tensor fasciae latae (superficial layer) and rectus femoris and hip abductors (deep layer) the joint capsule was exposed and with a curved special PAO chisel the first partial ischial osteotomy was performed. Further the pubic cut was performed after correct placement of the cutting guide and then the iliac cut (Fig. 8) was done with an oscillating saw after correct placement of the guide. To complete the partial ischial cut a straight chisel was used along the last

Left hemipelvis: Illustration of two-parts guide (red and green)

Figure 2a: Medial view

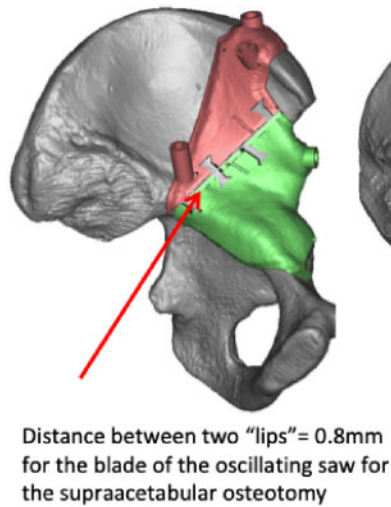


Figure 2a: Anterior view

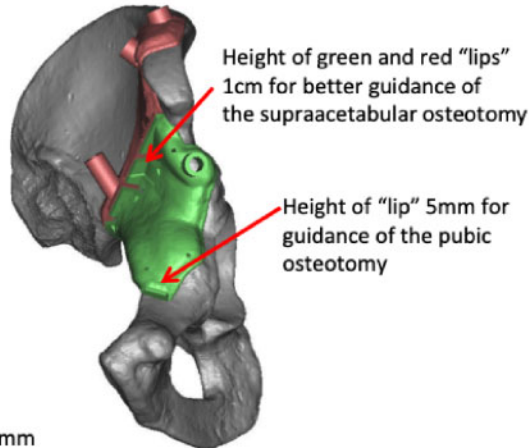


Fig. 2. Virtual 3D shaped guides fitting (red and green) on bone surface, showing the guided cut for the iliac bone. (a) Left hemipelvis from a medial view and (b) from an anterior view. The guides are broad but not bulky.

Left hemipelvis: Verification of fitting: use of a bridge between red and green part

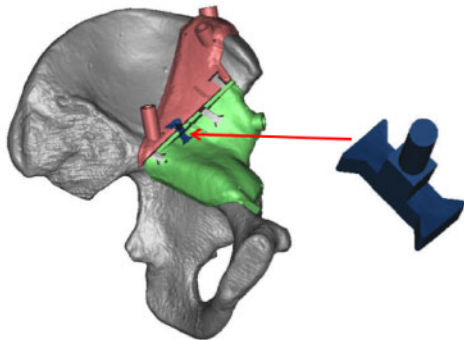


Fig. 3. This blue fixation guide (named bridge) was used to verify the optimal fit between the two guides (red and green).

cutting guide until the acetabulum became free. With a supra-acetabular Schanz screw the acetabulum was oriented in a preliminary position with more lateral coverage. Furthermore, the reorientation guide was placed (Fig. 9) to achieve the most accurate and particularly the planned acetabular orientation. A preliminary fixation with pins was done and the planned three screws were placed accordingly. The complete surgical plan is depicted in Figs 2–6 and intra-operatively executed in this exact way.

Bone quality

All eight specimens were classified arbitrary in 'good', 'moderate' and 'poor' bone quality.

Post-surgical imaging

Computer tomographic images were acquired postoperatively. This needed a transportation of the cadavers in another building.

Measurements

Pre- and post-operative measurements were obtained from the CT scans of the following parameters: (i) LCE [14]; (ii) acetabular index (AC) [15] and (iii) acetabular anteversion (AcetAV) angles [16, 17]. These parameters were measured from a 3D segmented model in frontal, sagittal and transverse planes.

Statistics

Statistical analysis was conducted using IBM SPSS Statistics v24.0 (SPSS, Chicago, IL, USA). Descriptive statistics, one-way univariate analysis of variance and a paired Student *t* test, was used to compare preoperative planned and postoperative LCE angles, AC angles, AcetAV angles and position of the centre of rotation. Statistical significance was considered when $P < 0.05$.

RESULTS

Bone quality was poor in four, moderate in two and good in two specimens. Application of the guides through the standard modified Smith-Peterson approach and performance of the osteotomies, reorientation and fixation was challenging in four out of the eight cadavers because of the osteoporotic very soft bone. In two cadavers, the Schanz

Left hemipelvis: Fixation of the 2 guides using K-wires

Figure 4a: Medial view

Figure 4b: Lateral view

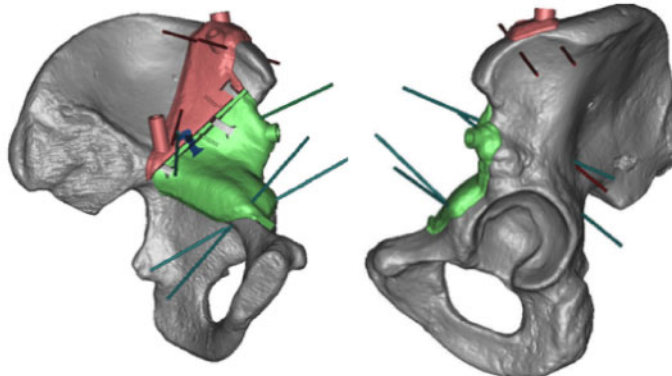


Fig. 4. These figures show a medial view (a) and a lateral view (b) of a left hemipelvis in the phase of fixing the guides with K-wires.

Left hemipelvis: “Drilling concept” for guiding osteotomy 4

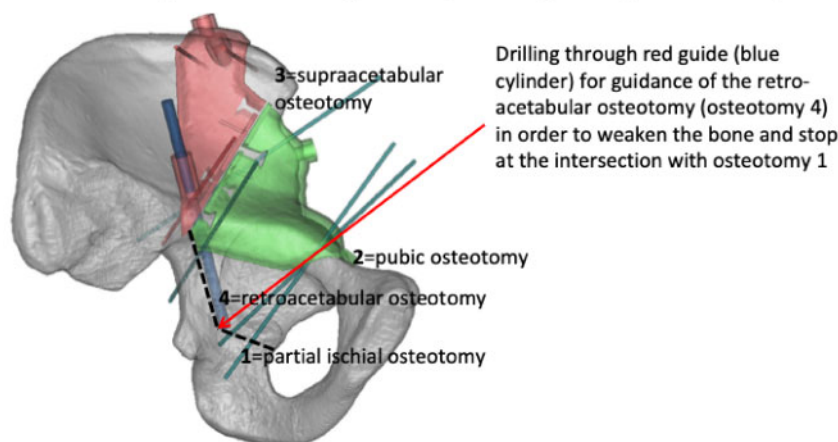


Fig. 5. The blue cylinder is showing the retroacetabular guidance. The retroacetabular osteotomy was not guided for a chisel. The angulation and the distance was planned and drilled as far as needed to meet the partial ischial osteotomy, which was the first osteotomy performed.

screws were even pulled out and could not be used for repositioning and reorientation, which made the operation impossible and these two cases were excluded from further analysis. However, the postoperative analyses showed that the cutting planes were completely extra-articular and the posterior column intact in all eight specimens.

The mean difference between the post-operative measured result and the planned preoperative calculated correction were as follows: 6° (SD $\pm 4^\circ$) for LCE angle, 5° (SD $\pm 3^\circ$) for AC angle and 15° (SD $\pm 11^\circ$) for AcetAV angle. Outliers, defined as more than 10° difference, were only seen in cadavers with moderate and poor bone quality.

The detailed information about every cadaver is depicted in Table I.

DISCUSSION

PAO allows for powerful correction of abnormal acetabular morphology. The goal of this correction is to enhance the function and preserve the durability of the native hip joint. While the technique of PAO has been well-described since its inception [13], it remains a technically demanding procedure, with significant risks of complications [4, 5] and an initial learning curve [3]. To aid with osteotomy accuracy and reliability, a number of adjunctive surgical tools have been used including navigation and computer guidance. This study presents the initial experience with patient-specific cutting guides in PAO, with the purpose of understanding the potential intra-operative feasibility issues and accuracy associated with use of these 3D, image-based guides.

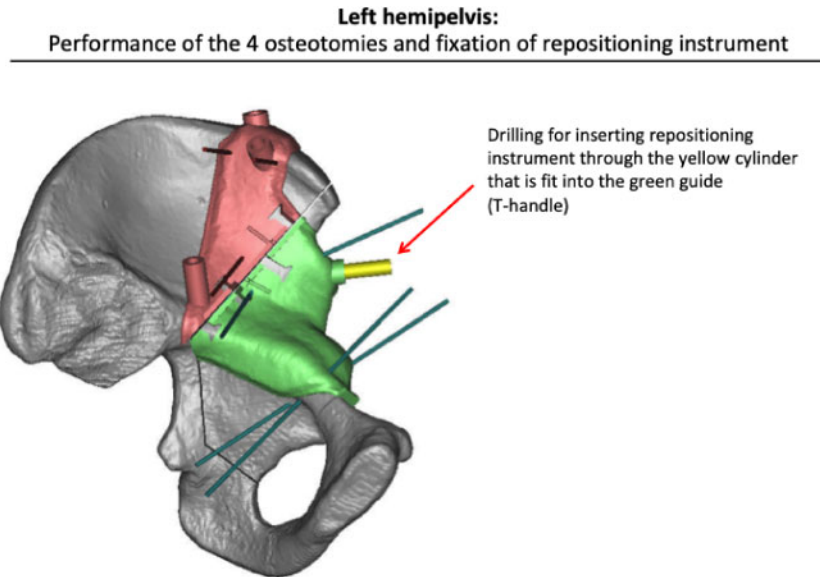


Fig. 6. After completing all the osteotomies the Schantz screw was inserted (here depicted as a yellow cylinder).

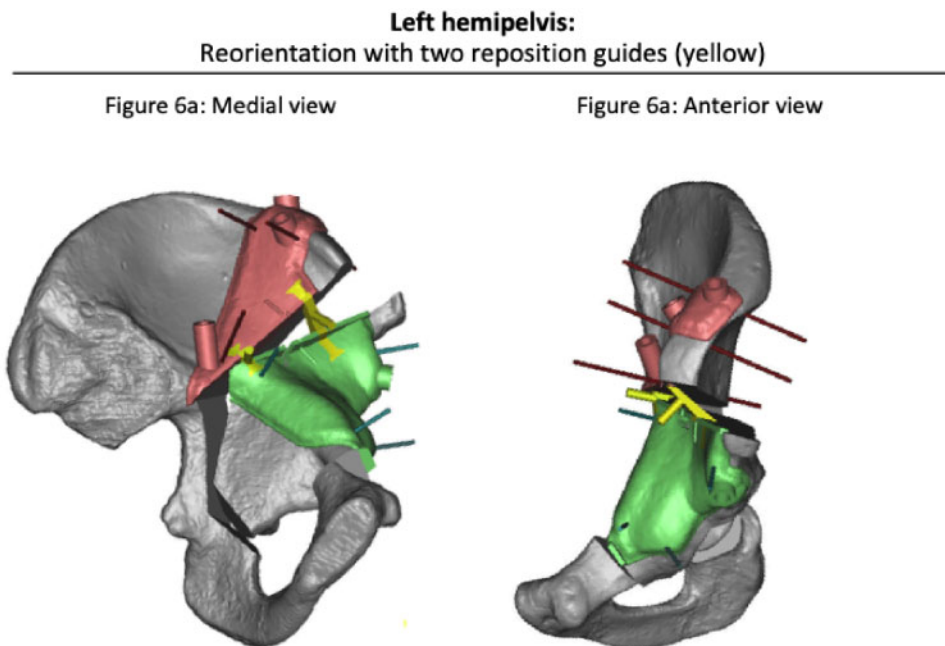


Fig. 7. Reorientation of acetabular fragment as defined by reorientation guides (yellow) according to virtually planned correction (3matic® software). (a) Medial view of a left hemipelvis and (b) an anterior view.

Custom made cutting and/or reposition guides have been used in a number of other surgical fields, including upper extremity [18–21], maxillofacial [22, 23], micro-vascular [24], knee [25, 26] and veterinary [27] procedures. Likewise, a number of procedures about the hip, including total hip arthroplasty [28, 29], hip resurfacing

[30–32], pelvic oncology [33, 34] and femoral deformity correction [35], have benefitted from computer assistance. While custom made guides have been employed in certain pelvic osteotomies [9–11], we found only one work of a Chinese group applying custom made 3D guides for PAO [12]. Although, in this study was stated the surgery was



Fig. 8. The two cutting guides fit perfectly on the bone and were fixed with pins. The surgeon performs the iliac cut of this right cadaver hemipelvis. A lateral retractor is protecting the hip abductor muscles.

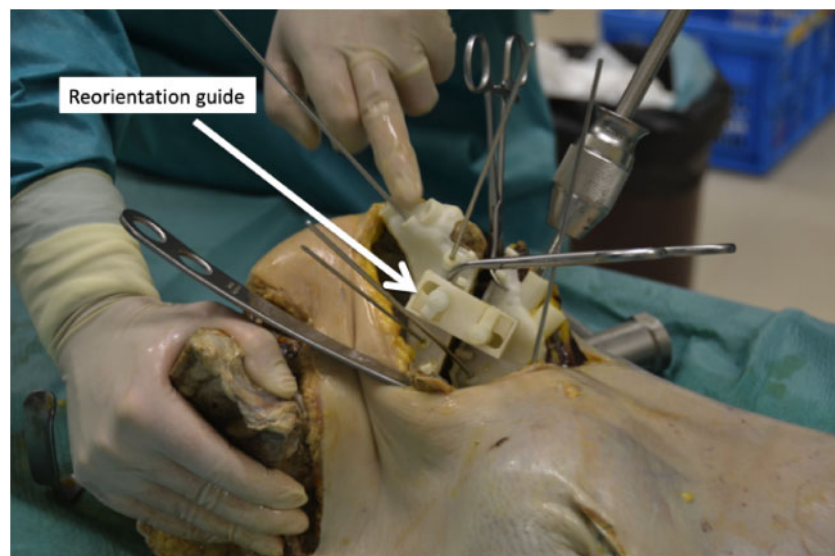


Fig. 9. In this left cadaver hemipelvis the Schantz screw with handle is seen and the reorientation guide is placed to hold the acetabulum in the planned place before fixing with pins and then screws.

performed according to Ganz *et al.*, the four osteotomies were performed with the oscillating saw, which is contradictory to the surgical technique described by Ganz. In particular, the partial ischial osteotomy is not possible to perform without an extensive soft tissue stripping.

The question regarding feasibility performing a PAO with cutting and repositioning guides can be answered with yes, but only in cadavers with good bone quality. The standard modified Smith-Peterson approach without extension of the skin incision or surgical dissection was used in all cases. No

separate surgical incisions were needed, as in the case of certain navigation systems or systems in which supplemental pins are required. The guides had an accurate and reproducible fit to the host bone. Importantly, the guides offered reliable positioning and execution of the planned osteotomies, with accurate approximation of the virtual osteotomy planes. However, the main technical challenge was the very soft bone in these old cadavers, which was the reason to exclude two cases and in two other cases the difference between the planned and performed LCE was more than expected with

Table I. Overview of the results of all the six cadavers

<i>Cadaver</i>		<i>Bone quality</i>	<i>LCE (°)</i>	<i>AC (°)</i>	<i>AcetAV (°)</i>
1	Preop	Good	30	−13	20
	Planned		43	−1	28
	Postop		42	−2	22
	Diff(planned-postop)		1	1	6
	Planned correction		13	12	8
	Obtained correction		12	12	2
2	Preop	Poor	31	−10	24
	Planned		47	3	37
	Postop		36	−5	12
	Diff(planned-postop)		11	8	26
	Planned correction		16	13	14
	Obtained correction		5	5	12
3	Preop	Moderate	45	−2	21
	Planned		61	11	32
	Postop		54	4	26
	Diff(planned-postop)		7	7	5
	Planned correction		16	13	11
	Obtained correction		9	6	6
4	Preop	Good	43	−7	23
	Planned		58	6	32
	Postop		54	0	26
	Diff(planned-postop)		4	6	6
	Planned correction		15	14	9
	Obtained correction		11	7	3
5	Preop	Moderate	42	−3	13
	Planned		55	9	24
	Postop		53	8	7
	Diff(planned-postop)		2	1	17
	Planned correction		13	12	11
	Obtained correction		11	11	6
6	Preop	Poor	32	−38	−12

(continued)

Table I. (continued)

<i>Cadaver</i>	<i>Bone quality</i>	<i>LCE (°)</i>	<i>AC (°)</i>	<i>AcetAV (°)</i>
	Planned	47	−23	−19
	Postop	38	−31	11
	Diff(planned-postop)	10	8	30
	Planned correction	16	14	7
	Obtained correction	6	7	24
Mean 1–6	Diff(planned-postop)	6	5	15

A complete overview of the results regarding preoperative, planned and postoperative measured correction in the CT scans.

LCE, lateral centre edge angle; AC, acetabular index; *AcetAV*, acetabular anteversion angles; COR, centre of rotation; Diff(planned-postop), difference (planned-postoperative).

11° and 10°, respectively, and in the *AcetAV* with 26° and 30°, respectively. In the other four cases, the difference from planned to perform LCE was 1°, 2°, 4° and 6° and *AcetAV* was 5°, 5°, 6° and 17°. Of course a difference of 17° in the *AcetAV* is not acceptable and can only be explained by the soft bone which was impressed while positioning re-orientation guide or even more likely there was a loss of the position during the transport in the other institution to perform the CT-scan especially in the four specimen classified as moderate and poor bone quality. A limitation is that there were no quantifying measurements of the bone quality and the surgeon only made the bone quality classification poor, moderate or good arbitrary after performing the PAO.

However, most likely this challenge would not be faced *in vivo* since the patient group requiring PAO is young and usually has very good bone quality. Certainly, further *in vivo* studies would have to confirm the hypotheses that in the young patients with good bone quality the precision would be better.

In the 30 years follow-up study of the Bernese group [36] an inaccurate post-operative acetabular position was a risk factor for earlier osteoarthritis. Therefore, the here shown guided technique to get the optimal postoperative position of the acetabulum might be a reasonable method in doing so.

Further limitations of this new technology include the cost and time associated with the design and manufacturing of the osteotomy guides. There is time also spent by the surgeon to perform the virtual osteotomy and correction, which can be a challenge for a non-experienced PAO surgeon were exactly to place the correct cuts and to which extent the correction should be performed. To which extent the correction should be performed is still debated and especially is not known for the 3D orientation measured on a CT-scan.

This technology at present relies on the use of a pre-operative CT for manufacturing. Finally, while osteotomy guides should not substitute for adequate training in this complex procedure, further studies should examine whether this technology offers added benefit to the experienced PAO surgeon, or have a preferential role for those in a learning period.

Cutting- and reorientation guides aimed to assist the iliac, posterior column and superior pubic ramus cuts as well as acetabular reorientation. However, the partial ischial cut seems not to be possible to guide when respecting the true anatomy. Especially for the less experienced PAO surgeon this usually first performed partial ischial osteotomy is the most challenging and also the most dangerous one not to insure the sciatic nerve since it is performed blind. Further studies are needed to find a way to guide this osteotomy as well to make this procedure less susceptible for complications for our patients. While we did not experience guide breakage, malfunction or poor mating of the guides with the bony anatomy, these remain theoretical concerns.

Moreover, the guides may obviate the need for approximation of pre-operative images as is required when fluoroscopy is used to compare pre-operative and intra-operative projections. Deviations that may exist between pre-operative weight-bearing radiographs may be mitigated by the patient-specific guides, and minimizes the operator-dependency associated with intra-operative fluoroscopic imaging. A further additional limitation of this initial pilot study includes the relatively small sample size.

This is the first study that demonstrates that a patient-specific virtual PAO could be translated to the cadaveric setting using the true technique of the PAO respecting anatomy and approach as it has been described. The use of 3D cutting and reorientation blocks for PAO was possible

through a standard Smith-Peterson approach without extension and revealed accurate fit to bone, accurate positioning of the osteotomies and acceptable planned corrections in cadavers with good bone quality. This new technology may have *in vivo* applications that will allow the orthopaedic surgeon to perform safe and accurate osteotomies, reorient the acetabulum exactly as individually, pre-operatively planned and therefore optimize load distribution without compromising on range of motion. However, this guidance should not substitute for excellent anatomic knowledge and a fellowship in reconstructive hip surgery to gain experience in PAO surgery.

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CONFLICT OF INTEREST STATEMENT

C.D. is co-owner of a patent on surgical guides (Patent PCT/EP2012/059168).

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